Eyes Can See Clearly Now

MILLIONS of people use eyeglasses or contact lenses to correct their vision, and many are opting for laser eye surgery. But determining the needed correction is not an exact process. When we have our eyes checked, we sit in a darkened room, peer through a device called a phoropter, and look at a focusing target, often an eye chart, projected in front of us. As we read the chart, an optometrist or ophthalmologist changes the lenses we're looking through while we repeatedly answer the doctor's only question: "Which one looks better—number one … or number two?"

A new optical device, called the microelectromechanical systems– (MEMS-) based adaptive optics phoropter (MAOP), will greatly improve this process. It allows clinicians to integrate a computer-calculated measurement of eyesight with a patient's response to the target image. Patients can immediately see how objects will look—and the clinician can adjust the prescription—before they are fitted for contacts or undergo surgery. As a result, patients will experience better vision correction outcomes, especially with custom contact lenses or laser refractive surgery.

MAOP was developed in a collaboration among universities, national laboratories, and industry, including a team of researchers from Lawrence Livermore. Funded by the Department of Energy and the Center for Adaptive Optics—a National Science Foundation Science and Technology Center—the project brings together optical component manufacturers and one of the world's leading providers of custom contact lenses and refractive eye surgery equipment. The MAOP team received an R&D 100 Award for developing an eye-correction system that combines technologies to improve the diagnosis and treatment of eyesight aberrations and ophthalmic and retinal disease.

Livermore members of the MAOP team (left to right): Scot Olivier, Steve Jones, Kevin O'Brien, Don Gavel, Abdul Awwal, and Brian Bauman.

An Objective Measure of Eyesight

The current phoropter used to measure vision addresses only the lower-order aberrations, such as defocusing and astigmatism. MAOP is designed to help patients with higher-order problems, such as coma, spherical aberration, trefoil, and quadrifoil. Scot Olivier, who led Livermore's MAOP effort, says future versions of the system will incorporate retinal imaging, so clinicians can more successfully diagnose and treat retinal diseases—such as retinitis pigmentosa, glaucoma, diabetic retinopathy, and macular degeneration—that cause blindness.

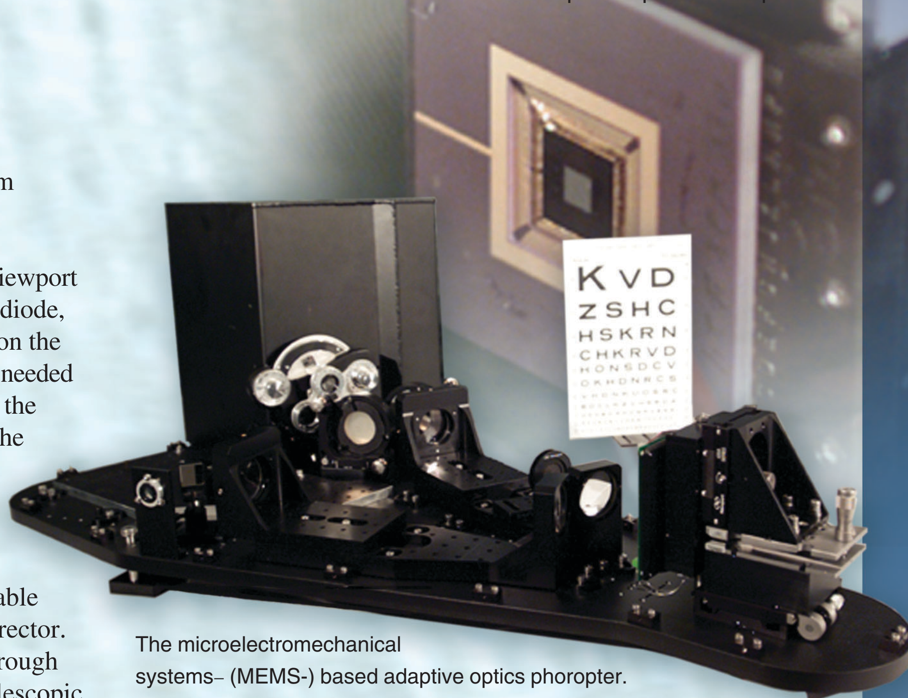
MAOP combines adaptive optics technology—a technology used on the world's largest telescopes for high-resolution imaging of astronomical objects—with MEMS deformable mirror technology. By using the MEMS deformable mirror, says Olivier, the team significantly reduced the size of the phoropter and could build it with commercial components, thus making MAOP compact and affordable.

Adaptive optics compensates for optical aberrations by controlling the phase of the light waves, or wavefronts, as they hit the retina—much like waves breaking on a shoreline. The optical structures in the eye, particularly the cornea and lens, can distort these wavefronts and thus produce the aberrations we encounter in our natural vision. An adaptive optics system measures aberrations with a wavefront sensor and uses a wavefront corrector to compensate for the distortion.

With MAOP, a patient looks through the phoropter viewport at a focusing target. A light source, a superluminescent diode, is projected into the patient's eye and creates an image on the retina. A flip-in mirror allows a computer to calculate the needed correction. By pushing a button, the clinician can apply the computer-calculated prescription and ask the patient if the image is clear.

A beam splitter can be incorporated with the system to combine these two steps. Then the patient can simultaneously view the focusing target while the computer corrects the aberrations. The MEMS deformable mirror uses a standard Shack–Hartmann wavefront corrector. Light from a laser or superluminescent diode passes through the beam splitter, flip-in mirror, adjustable lens, and telescopic lenses and is then reflected off the corrector. Another set of telescopic lenses directs the light through the eye and creates an image on the retina. The wavefront sensor sends information to the computer interface, telling the computer how to adjust the corrector.

MAOP is the first system to use the much smaller and less expensive MEMS deformable mirror for adaptive optics and ophthalmic applications. The wavefront sensor determines how much the wavefront is distorted as it passes through the eye's cornea and lens. A computer uses this information to create an internal, three-dimensional (3D) representation of the distorted wave. That 3D shape is then used to instruct the 144 MEMS actuators to move to positions that will minimize the distortion and "flatten" the wavefront.



The microelectromechanical systems– (MEMS-) based adaptive optics phoropter.

Hope for Fighting Retinal Disease

Because MAOP features a modular design, it can be adapted for other applications. Modules under construction will enable the system to also perform retinal imaging. Traditional retinal imaging systems cannot apply wavefront corrections and thus produce images with a limited resolution, which hinders a doctor's ability to diagnose early-stage retinal disease. Adaptive optics systems, which can correct wavefronts, produce far superior retinal images.

Higher-order aberrations, such as distorted vision from halos or glare, increase with an individual's age. Previous computer-calculated methods do not correct for these problems and have not produced acceptable results. MAOP not only measures and corrects these aberrations, but it also can be used to evaluate eyesight under conditions that limit vision, such as while driving at night.

Clinical studies at the University of Rochester, which were conducted with earlier versions of MAOP, showed the benefits of correcting higher-order aberrations. Patients with extremely poor vision—say 20:400, which is far below the normal 20:20 eyesight—reported significant improvement when these aberrations were corrected. One patient's vision became 24 times better.

With MAOP, clinicians can train their staffs to operate a single instrument with multiple functions and applications. The system can also collect and store patient information—before and after the correction is applied and the patient's input is received—to provide an eyesight history for help with later diagnosis. A MAOP system outfitted with retinal imaging could be used to test new therapeutics in clinical trials and provide objective measurements of a therapy's effectiveness.

MAOP is the first system to measure higher-order aberrations in the human eye, apply corrections, and immediately allow the patient to see the results. It's an innovative technology for early detection and treatment of retinal diseases that cause vision loss and blindness. And it will improve optical treatment for the millions of people who depend on vision correction just to make it through the day.

—Sharon Emery

Key Words: eyesight correction, microelectromechanical systems– (MEMS-) based adaptive optics phoropter (MAOP), R&D 100 Award, retinal disease.

Acknowledgments. In addition to the Livermore team, collaborators included Ian Cox: Bausch & Lomb; Paul A. Bierden: Boston Micromachines Corp.; Stephen Eisenbies, Steven Haney: Sandia National Laboratories; David Williams: University of Rochester; and Dan Neal: Wavefront Sciences.

For further information contact Scot Olivier (925) 423-6483 (olivier1@llnl.gov).